Does Competition for Transplantable Hearts Lead to List Gaming?

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Abstract

This paper examines whether heart transplant centers (TCs) respond to competition from other transplant centers by upgrading the listing status of less severely ill patients to gain access to scarce transplantable organs. We model the proportion of patients listed in the most severe listing category as a function of the competitiveness of the Organ Procurement Organization (OPO) within which the TC participates. In addition, we study the differential effect of competition before and after the United Network for Organ Sharing (UNOS) changed the criteria that transplant centers must follow when listing patients for heart transplant. Daily and quarterly observational data were obtained from UNOS' Organ Procurement Transplant Network (OPTN) for 1995 to 2000 to form a six-year panel. The unit of analysis is the transplant center clustered by market. We define the OPO as the market since cadaveric hearts are almost exclusively allocated to TC's within the OPO where the organ was harvested. Our data set includes information about listed patients who are waiting for a transplantable heart and patients who received heart transplants. Available information at the TC level includes aggregate patient demographic characteristics (age, race, blood type, gender), payment information (insurance status) listing status (illness severity at which patient is listed), and amount of time on the waiting list.

We model the impact of TC competition on TC patient-severity listing practices by fitting our data to a logit model for proportions where the dependent variable is defined as the logit of the proportion of a TC*'s* listed patients in the most severe illness category. Covariates include adaptations of the Herfindahl index, as well as market specific measures of the size and influence of the other centers competing in the market. We control for potential confounding variables by including patient gender, blood type, and the average age of listed patients. All models assumed random effects to account for the market level clustering of the data.

We find that prior to the UNOS policy change, centers in more competitive OPOs had significantly higher proportions of patients listed in the most severe status, suggesting that these centers may have been responding to their incentive to game the system. Significant gaming effects were not found following UNOS' listing policy change, which suggests that the new listing status might have reduced the incentive to inappropriately upgrade listings. Policymakers need to consider whether the incentives created by the allocation mechanism for transplantable hearts are properly aligned with societal goals.

I. Background

According to the Centers for Disease Control [and Prevention] (CDC), more than 60 million Americans have some form of cardiovascular disease and over 2,600 deaths occur each day due to causes attributed to conditions such as heart disease, stroke, and congestive heart failure. Heart disease and stroke are the principle causes of mortality among all ethnic and racial groups. Often, cardiac transplantation is one of the few treatments available for patients suffering from chronic heart failure [Young, (1998)]. The United Network of Organ Sharing (UNOS) reports one-month, one-year, and three-year heart transplant survival rates of 92.4%, 84.8%, and 77.1%, respectively [Transplant Patient Data Source 2000]. In the United States, the demand for heart transplantation has grown, routinely exceeding the supply of available transplantable cadaveric hearts. For example, in 1999, there were about 4,200 patients waiting to receive a heart on any given day of the year, while only about 2,180 patients actually received a heart transplant in 1999 (Figure 1). Approximately 700 patients died during that year while waiting to receive a cadaveric heart.

Despite the fact that cadaveric heart donors remain in short supply, there were 172 medical centers in the United States with cadaveric heart transplant programs between 1995-2000. Of these programs, about 125 per year were centers that were not exclusively pediatric centers. The majority of these centers were small when measured by the number of transplants performed or the number of patients listed with the center as waiting for a transplant. For example, in 1999, the median number of transplants performed by a center was 12, and the median number of patients listed on any given day was 11. The prevalence of many small transplant centers (TC) in the United States is particularly troubling given the documented inverse relationship between the volume of yearly transplants performed by a center and patient outcomes as measured by post-transplant survival rates [Hospenhud et al. (1994), Laffel et al. (1992)].

With so many centers and so few available hearts, and given the heightened interest of managed care organizations to contract with fewer centers that perform higher volumes of transplants at lower costs, some researchers have raised the possibility that TCs might compete with each other by overstating the severity of their patients in order to gain access to cadaveric hearts [Votapka et al. (1995)]. As Votapka et al. (1995) point out, this upstaging of patient severity could occur by admitting patients to the intensive care unit (ICU) before they actually need to be admitted, or by using certain intravenous inotropic agents, indwelling hemodynamic monitors, or mechanical assistance, all of which allow the patient to be listed in the highest priority listing category. If competition of this sort does exist, then it would be inefficient, resulting in a distribution of transplantable hearts that is inconsistent with national goals. Inappropriate listing practices also raise the possibility of increased health care expenditures associated with unwarranted ICU days and unnecessary treatments and therapies.

The rules governing the distribution of cadaveric hearts in the United States are developed and enforced by UNOS, a non-government entity appointed under contract by the U.S. Department of Health and Human Services. UNOS was created after the 1984 passage of the National Organ Transplantation Act (NOTA). NOTA specifically outlawed the sale of human organs, initiated the development of a national system for organ sharing called the Organ Procurement and Transplant Network (OPTN), and created a scientific registry to collect and report transplant data.

In its role as regulator of transplantation, UNOS develops and enforces policies and procedures for all solid organ transplants. UNOS also manages the national transplant waiting list and matches recovered organs with waiting recipients. UNOS also develops organ allocation procedures and works with Organ Procurement Organizations (OPOs) to allocate donated organs to the appropriate patients listed at TCs. OPOs are regional organizations and are responsible for activities pertaining to organ donor awareness and organ recovery. UNOS is comprised of 55 OPOs, with each of the 172 TCs affiliated with just one OPO.

For cadaveric hearts, variables other than listing acuity status that influence organ allocation decisions include tissue matching, donor and recipient blood type, and donor and recipient age. In addition, patients placed on the transplant waiting list are assigned a listing status, and priority is given to patients with a more severe illness status. Although the listing status is just one of the variables that influences the final organ allocation decision, designation of the category is under the clinical discretion of individual treating physicians and/or the transplant team located at the TC. UNOS changed the listing rules for hearts in January 1999. Prior to 1999 patients were listed in only two categories (Status 1 and Status 2). Patients assigned Status 1 were of an illness scale that portended a life expectancy of less than six months without a transplant. UNOS ultimately changed the listing status because it believed that the Status 1 category did not adequately distinguish between the sickest patients. Beginning in 1999, Status 1 was divided into two new categories: 'Status 1A' and 'Status 1B'. The distinction between these two categories primarily pertains to life expectancy. Status 1A is reserved for patients with a life expectancy of less than one month (requiring indwelling hemodynamic catheter monitoring and/or mechanical heart assist device placement within the first 7 days), while Status 1B is reserved for patients with a life expectancy between one and six months.

Unlike other organs such as kidneys and livers, which may be shared between OPOs, hearts are unique in that they are almost always transplanted by one of the TCs within the OPO where the organ is recovered. This is because hearts have low tolerance for extended cold ischemia time. Kidneys can be preserved for up to 72 hours, and livers can be preserved up to 24 hours. But hearts must be transplanted within 4 to six hours after being harvested (Pfulgfelder et al. 1989), which precludes them from being transferred outside of the OPO to other geographic regions. From a research perspective, the fact that hearts generally are recovered and transplanted within OPOs is convenient, since one can view the OPO as a 'market' and the TCs within that OPO as the 'competitors' who compete for the recovered hearts by virtue of the patients that are listed with these centers. From a policy perspective, some analysts have questioned the equity of local rather than national distribution of recovered hearts, but the short ischemic time seems to prevent moving to a national list as has been done for other organs (e.g., kidneys, which require national sharing for zero human leukocyte antigen (HLA) mismatched organ-recipient pairings).

OPOs are not uniform in terms of the number of TCs, or the size or volume of transplants performed by each center within the OPO. Therefore, in economic terms, some OPOs may be considered monopolistic, since the OPO has only one TC and will receive all hearts recovered by that OPO, while other OPOs are relatively competitive, with as many as 8 TCs eligible to receive recovered hearts. OPOs with multiple TCs may be more or less competitive depending on the size and volume of individual TCs within the OPO. Hence, this unique definition of a 'market' (i.e., OPO) and its competitors (i.e., TCs), and the variation across markets, allows us to examine the following research questions and hypotheses.

Research Question 1: Do patient listing practices differ between TCs in more competitive and less competitive OPOs?

Hypothesis: Because they are competing for scarce hearts, TCs in more competitive OPOs will be more likely to list patients in the highest severity listing status (Status 1 prior to 1999, and Status 1A after 1999) relative to TCs in less competitive OPOs.

Research Question 2: Did listing practices of TCs in more competitive markets change with UNOS' implementation of new listing categories, which became effective in January of 1999?

Hypothesis: The incentive to upgrade the list in more competitive markets would still exist after the UNOS policy change.

II. Conceptual Framework:

The conceptual framework that leads to our empirical estimation can be considered a three stage signaling game with $n+1$ players, including an OPO, and n transplant centers, where n varies according to each particular OPO. In the first stage of the game, TCs accumulate patients waiting to receive transplantable hearts, and signal their patient characteristics to the OPO. In the second stage of the game, nature allocates organs to the OPO as individuals expire and their families agree to donate their organs. In the third stage, the OPO allocates organs to the TCs based on the signals received from the TCs and allocation rules and priorities established by UNOS. We hypothesize that TCs have an incentive to upgrade the signal (i.e., list their patients in a more severe priority status) submitted to UNOS as long as the expected benefits of doing so outweigh the expected costs. We also hypothesize that the incentive to upgrade the signal increases with market competitiveness. The use of pulmonary artery monitoring catheters, intravenous inotropic therapy, and left-ventricular mechanical assist devices (LVADs), are methods to make the upgrade consistent with UNOS listing requirements, since without these support measures patients would have a life expectancy of less than 30 days. Hence, our conceptual framework suggests that in equilibrium, a TC's listing practice is a function of the overall competitiveness within the OPO, which is determined by the size and activity of the competing TCs within the OPO.

In order to estimate our empirical models, we define OPO competition by creating the Hirschman-Herfindahl Index (HHI). The HHI is commonly used for measuring the degree of competitiveness within a market, and is a non-linear function of the individual market shares of each competitor within the market [Baker, (2001)]. The formula for the HHI is:

$$HHI_i = \sum_{j=1}^{n_i} (s_{ij})^2 \tag{1}$$

where i=1,…,I indexes OPOs (i.e., markets) and j=1,…,n_i indexes TCs within OPOs.

III. Literature Review:

Although several published studies examine various aspects of heart transplantation and competition in health care markets, no studies directly examine TC-specific listing practices as a function of OPO competition, which is the focus of our study. Still, these other published studies are useful for our analysis, so we briefly review the literature below, categorizing the studies by their objectives.

Competition in Health Care

Various models have been used to assess the effects of competition on firm behavior. The results of these models suggest that competition eliminates less efficient producers and rewards more efficient producers[1]. While this might suggest that competition is generally associated with more efficient allocation of resources among producers this is not always the case, particularly in health care markets [Robinson, (2001)]. A recent special issue of the journal, *Health Services Research*, contained several articles that reviewed the literature on competition in health care markets, particularly hospital and health insurance markets [Baker, (2001), Morrissey, (2001), Mark & Coffey, (2001)], so in the interest of brevity, we refer the reader to those articles rather than review the literature here.

Competition Among Transplant Centers:

Whellan et al. (2000) examined the behaviors of heart TCs operating in the Delaware Valley OPO, which serves the greater Philadelphia, PA, metropolitan area. The authors studied the relationship between TC practices and access to donors and survival rates for transplanted patients. They analyzed data for the 662 patients on the status 1 list at one of the four adult heart transplant centers in the OPO from 11/1/92 through 12/31/95. The authors hypothesized that program specific listing decisions would lead to differences in status 1 waiting times, the probability of transplantation, and the probability of survival while awaiting transplantation. The authors specifically examined whether patients were moved from Status 1 list to Status 2 list before transplantation (a reflection of clinical attempts to manage patients with more

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[1] The two classic examples are the Bertrand model of price competition and the Cournot model of quantity competition.

conservative measures), whether the patient received mechanical assistance, and the percentage of a patient's time on the status 1 list prior to transplant. The authors' major finding was that transplant centers' practice patterns affected the probability of transplantation and overall survival of status 1 transplant patients. Significant differences were found across centers in the use of mechanical assistance, movement from the status 1 to the status 2 list, and waiting times. The authors found that center specific characteristics were important predictors of the likelihood of transplantation and the results suggest the importance of unmeasured TC specific clinical practice patterns. The authors speculate that the differences that they observed may be due to the willingness of some centers to use marginal donors, defined as a less than optimal match between the organ donor and organ recipient, which can be due to less than optimal tissue matching, as well as the overall quality of the donated organ.[2] What could not be assessed was individual listing practices because of the use of an administrative database.

Relationship Between Volume and Survival:

Hosenpud et al. (1994) studied the relationship between TC volume and survival by using UNOS registry data from 1987 to 1991. to determine whether the number of transplants performed at a TC determined patient survival rates. The authors modeled the likelihood of survival as a function of center specific transplant volume, adjusting for a variety of factors including, repeat transplantation, medical condition at the time of transplantation, presence of congenital heart disease, and year of transplantation. They found that centers performing less than nine transplantations per year experienced significantly higher patient mortality than TCs performing nine or more transplants, with

[2] Some examples of factors related to marginal donors include the use of hearts from older donors, donors with preexisting coronary artery disease or valvular heart disease, and victims of carbon monoxide poisoning (Rayburn et al 1998).

the increased risk of mortality at one and 12 months, relative to a center performing at or above the nine transplant threshold, being 40.3% and 33.1% respectively. While the authors note that more than 50% of the TCs in the United States are performing less than nine transplants, they also note that they were unable to detect any differential effect on mortality between TCs performing between 9-11 transplants per year, or those meeting the Medicare eligibility requirement of twelve or more heart transplants per year.

Laffel et al. (1992) analyzed transplant data from 1984-1986 for 56 TCs in the United States to examine the relationship between experience and mortality. The authors found that there was an 'institutional learning curve,' with rates for the first five transplantations resulting in a significantly higher level of mortality than subsequent transplantations. Although the authors were unable to identify what aspects of patient care were affected by learning, they did find that previous training in heart transplantation for cardiologists and the presence of a transplant coordinator were correlated inversely with patient mortality.

Relationship Between Distance and Mortality:

Rodkey et al. (1997) examined whether mortality was related to the distance between a patient's home and the transplant center, noting that it is becoming increasingly common for insurers and other third party payers to contract with regional heart transplantation referral centers, requiring many patients to travel long distances for transplants and post-operative care. The authors examined 312 adult transplant recipients from one TC who survived at least three months. The authors' analysis revealed no statistically significant relationship between distance from the patients' home to the TC and mortality. Although this result must be interpreted with caution since the study included data from only one TC, it suggests that consolidating transplants into regional centers in order to take advantage of the positive volume-outcome relationship and potential economies of scale (i.e., lower fixed costs), may be a feasible strategy.

U.S. and U.K. Comparisons in Cardiac Transplantation:

Although heart transplant science is virtually the same in the United States and the United Kingdom, both countries differ significantly in the manner in which cardiac transplant care is organized and financed. Anyanu et al. (1999) used data from both countries to identify if organizational and financial differences led to differences in transplant practices. The authors identified several notable differences, including the number of centers performing heart transplants (164 in the U.S. v. 9 in the U.K.), the mean number of transplants per center per year (14 v. 34), and the number of heart transplants per million population per year (8.8 v. 5.4). The authors also found that older patients (>65 years of age) were much more likely to be on the transplant list in the United States, and that patients listed in the U.S. were much more likely to be placed on ventricular assistance (OR=8.0), or intravenous inotropes (OR=4.9), despite the fact that there was no significant difference in indications for heart transplant. With respect to the use of ventricular assistance and inotropes, the authors state that the UK does not give priority to patients requiring either of these interventions, whereas these treatments provide a patient with higher priority on the heart waiting list in the United States. The authors suggest that "the prioritization of status 1 patients in the U.S. may result in a lower threshold for intensive care admission and institution of inotropic support. Inotropes may therefore be used in some US recipients for the primary objective of increasing the chances of receiving an organ, and hence the difference in organ allocation criteria could contribute to the observed difference in the use of inotropes" (page 300-301). The authors further-suggest that, "the net result could be that the U.S. patients enter transplantation in a healthier state because of the use of inotropes. This increased use of inotropes could contribute to the improved patient survival because of improved end-organ function at transplant (86% one year survival rate in the U.S. vs. 77% in the U.K.).

Costs of Heart Transplantation:

Votapka et al. (1995) retrospectively analyzed charges for 107 adult patients undergoing heart transplantation between August 1988 and September 1993 at the St. Louis University Medical Center. Charges were analyzed for both status 1 and status 2 patients at the time of donor organ acceptance. Charges were converted to 1992 U.S. dollars, and included pre-transplantation and post-transplantation charges as well as the costs of surgery and organ procurement. The authors found a large, significant difference between status 1 and status 2 patients, with higher charges for status 1 patients due to higher inpatient charges resulting from longer lengths of stay (49.2 days v. 17.6 days). The reported total charges were $239,375 for status 1 patients and $128,593 for status 2 patients.

Although the authors identify the differences in charges by patient listing status, they acknowledge that there are advantages to admitting patients to the intensive care unit (ICU) before they are actually in need of ICU services. The advantage lies in accrued time on the status 1 list, which can increase the likelihood of receiving a transplantable heart. The authors state that "the net effect of these practices (placing patients in the ICU) are to globally increase transplant costs, which results in unfair, non-uniform distribution of donor organs (p. 371)." The authors' further state; "we believe that standards that prioritize candidates according to severity of illness favor prolonged hospitalization and may lead to inequitable allotment of donor organs" (p. 372).

The national cooperative transplant study showed a range of hospital charges from $8,173 to $1,290,035 [Starling et al., (1998)]. In 1993, actuaries estimated the total charges for a heart transplant to be $209,000 in the United States. The average reimbursement by a capitated provider was $98,500. Starling also reports data from two states. For the period 1992-1994 in Ohio, the average cost of pre-transplant care was $42,988, while the average cost of post-transplant care was $107,066. In Pennsylvania in 1991, the average total hospital charge was $233,276. None of these studies separately report fixed and variable costs, but knowing that information is important for identifying economies that may result from increased volume in fewer TC's.

IV. Methods

Data

Data for this study were obtained from UNOS' Organ Procurement Transplant Network database (OPTN) and consist of quarterly 'snapshot' and daily average TC information (i.e., aggregated across all patients) from 1995-2000. The unit of analysis is the TC within the OPO. Our data include aggregate information on patients on the cardiac transplant waiting list at each center, including aggregate demographic characteristics (e.g., age, race, blood type), payment information (i.e., insurance status), listing status, and amount of time the patient has been on the waiting list. The data also contain aggregate TC level information on patients who received a heart transplant, including the same demographic, payment, listing and waiting time data.

There were 182 TCs in our data, however 10 of these centers did not perform heart transplants and were dropped. Of the 172 remaining centers, we eliminated centers that exclusively performed pediatric heart transplants. Pediatric TCs were eliminated because of the unique type of clinical syndromes and listing requirements for hypoplastic left heart syndrome patients, and since our focus is on centers performing adult heart transplants. The range of adult TCs was from a low of 120 centers operating in 2000, to a high of 129 centers operating in 1995.

Empirical Analysis

Since we hypothesized that TC listing decisions are a function of the amount of competition among centers in an OPO, and the scarcity of available donor organs, the goal of our empirical analysis was to determine whether the proportion of a center's patients that are listed as status 1 (pre 1999) or status 1A (post 1999) was a function of market competition.

Our dependent variable is the proportion of TC *j*'s patients in OPO *i* at time *t* that are listed in the most severe illness category (status 1 prior to 1999 and status 1A after 1999). The usual approach to model such data is to transform the dependent variable using a logit transformation:

$$\operatorname{logit}(p_{ij}) = \ln\left(\frac{p_{ij}}{1-p_{ij}}\right) \tag{2}$$

where p_{ij} is the proportion of patients listed in the most severe priority status at center *j* in OPO *i*. The logit transformation maps the proportion of status 1A patients, which is bounded by 0 and 1, to the real line. Given that there may be important OPO cluster effects, we fit our data to models that are appropriate for clustered data. Specifically, we fit both fixed and random effects models and selected our final model based on the results of Hausman's test. In each case the random effects specification was preferred. Therefore, the model we estimate takes the following form:

$$\operatorname{logit}\left(p_{ij}\right) = \alpha + \mathbf{x}'_{ij}\delta + \mathbf{w}'_{ij}\gamma + \varepsilon_{ij} . \qquad (3)$$

where $\mathbf{x}_{ij}$ is a vector of TC specific characteristics, including aggregate patient demographic characteristics, $\mathbf{w}_{ij}$ is a vector of OPO specific characteristics including the Herfindahl index, α, δ, and γ are model parameters to be estimated, and ε_{ij} is a zero-mean, normally distributed error term.

To account for the clustering of TCs within OPOs we assumed OPO-level random effects. Thus the error term is composed of a TC-specific error and an OPO-specific error, $\varepsilon_{ij} = \eta_{ij} + u_i$, where η_{ij}~N(0, σ^2), u_i~ N(0, τ^2), and Cov(η_{ij}, u_i)=0. This model accounts for the potential correlation between errors for TCs within OPOs via the common error component, u_i. Thus, the error terms for two TCs, m and n in the same OPO i are correlated: $Corr(\eta_{im} + u_i, \eta_{in} + u_i) = \rho$.

The regression coefficients can be interpreted as coefficients for linear models, except that the dependent variable is a log odds rather than a mean. Thus, δ_k represents the change in the log odds associated with a unit change in the k^{th} TC level predictor, holding all other predictors constant. Furthermore, the exponentiated coefficients represent odds ratios. For example, e^{δ_k} represents the effect of a one-unit increase of x_{ijk} on the odds of a center listing its patients in the highest priority status. To describe the marginal effect of covariates on the proportion of patients listed in the most severe status, first solve the logit model in equation 2 for p_{ij}, which yields:

$$p_{ij} = \frac{\exp(\alpha + \mathbf{x}'_{ij}\delta + \mathbf{w}'_{i}\gamma)}{1 + \exp(\alpha + \mathbf{x}'_{ij}\delta + \mathbf{w}'_{i}\gamma)} . \qquad (5)$$

The left-hand-side is now in the familiar probability scale, but the right-hand side is a non-linear function of the predictors. We can approximate the effect of increasing a covariate by one unit on the proportion of status 1a patients listed by the average center by taking the derivative of p_{ij} with respect to x_{ijk}:

$$\frac{\partial p_{ij}}{\partial x_{ijk}} = \delta_k p_{ij}(1 - p_{ij}) \tag{6}$$

We evaluate this product at the sample mean of p_{ij} and approximate the effect of the covariate near the mean of the response.

Because the variables that were used to create our dependent variable were average daily listings and not constrained to be integer values, 18 observations from smaller centers with no Status 1 or 1A listings were excluded from the analysis sample. This left a total of 712 observations, including 146 TCs from 55 OPOs between 1995 and 2000[3].

OPO market share is defined in two ways. First, we calculate market share as the total number of patients on a given center's heart transplant waiting list, divided by the size of the total OPO heart transplant waiting list. As we describe later, our listing data for each TC is the average number of patients on the waiting list on any given day in the calendar year.[4] However, what may be most important to TCs is the number of Status 1

[3] Although there were at most 129 TCs in any given year, there were a total of 146 centers across all years of data due to entry and exit of some centers.

[4] The daily average was calculated by summing the number of patients in each listing category for each day of the year, and then dividing by 365 days. The alternative to daily average data was quarterly data, but since the number of listed patients in many centers is low to begin with, we found that UNOS quarterly data, which represents a 'snapshot' at the TC on the last day of each quarter, contained a lot of zero values since on any given day, some TCs have zero patients listed. So, we asked UNOS to calculate daily averages for each year. Since patients remain on the list for more than one day in most cases, and can switch from one listing category to another, we are not able to identify the *total* number of patients on a TC's list during the *course* of the year. The alternative would be patient specific data that tracked all patients from time on list until time removed from the list. However, patient specific data was not available from UNOS.

or Status 1A patients in the market. Therefore, we also compute market share as each TCs share of patients listed as Status 1 or 1A in the OPO. In both cases, the HHI provides a measure of the degree of competition that TCs may face from rival TCs for scarce transplantable organs. In the extreme case, when there is only one TC in an OPO, that center will have a market share of 100% (since all patients listed in the OPO are listed at the only operating TC), and the relevant HHI will take on a value of 1[5]. At the other extreme, there are an infinite number of TCs in an OPO, each with less than one percent of the total market share resulting in an HHI near zero. In practice, the average OPO has three TCs with a mean HHI of about 0.66, suggesting that OPOs are typically somewhere in between monopoly and perfect competition. Typically the HHI is multiplied by 100, and the DOJ defines unconcentrated markets with values of HHI below 1000, moderately concentrated markets with values between 1000 and 1800, and highly concentrated markets with values above 1800. Although the HHI is primarily based on market share rather than number of competitors, it is influenced by number of competitors in the OPO since market shares often depend on the number of active competitors [Baker, (2001)].

We fit the model using feasible generalized least squares (FGLS), which produces efficient estimates. Ordinary least squares regression was first used to estimate the variance components, and FGLS estimates were then computed based on the estimated variances. Analyses were first stratified by time period corresponding to the UNOS policy change, and then pooled across the policy change period. In addition to the Herfindahl index, we also include as covariates the proportion of a center's listed patients that were female (poorer prognosis), O blood type (O recipients are doubly disadvantaged because donors can be used for all blood types in the status 1a category, therefore, their waiting times are typically longer), year dummy variables to account for potential time trends, and an interaction term between the policy change dummy and the Herfindahl index in the pooled models.

V. Results

Table 1 presents descriptive statistics for TCs by year. Notice that, in general, the number of transplant centers was relatively constant over time, but varied from a high of 129 in 1995 to a low of 120 in 2000. The average number of transplants was also relatively constant over time. TCs performed approximately 17.5 transplants per year, with substantial variation across centers. The lowest volume center performed no transplants in a given year, and the largest center performed approximately 100. The proportion of female transplant candidates rose only slightly from 18% on average in 1995 to 20% on average in 2000. Again, there was substantial variation across centers, with some centers reporting no female candidates and others reporting nearly all female candidates. The proportion of patients with type O blood was relatively constant at 55% across the six years of our sample.

We report the number and percentage of heart transplant candidates who were listed as Status 1, 1A, 1B, and 2 across the years of our sample. The proportion of patients listed as Status 1 increased over time prior to the splitting of Status 1 into two categories. The proportion of transplant candidates listed as Status 1 rose from 13% in 1995 to 19% in 1998. Again, there was substantial variation across clusters as seen by the large standard deviations relative to the average values. Also, there was at least one TC with no Status 1 patients, and at least one TC with all patients listed as Status 1. Only two years of data are available for the Status 1A category, but the data suggest that the proportion of patients listed as Status 1A also rose somewhat between 1999 and 2000.

Characteristics of OPOs are presented in Table 2. The average OPO contained between two and three TCs. The most competitive OPOs had 7 or 8 TCs, and there were 15 monopoly OPOs. The average Herfindahl Index based on the total waiting list rose over time from 0.52 in 1995 to 0.59 in 2000, suggesting that OPO markets became, on average, more monopolistic. The most competitive OPO had an index value of 0.22, while the monopolistic OPOs had index values of 1. In contrast to the Herfindahl based on the total waiting list, the Herfindahl Index based on the Status 1 list stayed at a relatively constant value of 0.53 over time. A similar trend was observed for the Herfindahl Index based on Status 1A listings. An analysis of these OPO level statistics over time, including an analysis of the stability of the HHI, suggests that the HHI is relatively stable within the same markets over time. Our measure of competition varied on average within a given OPO by a standard deviation of about 0.06 with the highest standard deviation being 0.33 and the lowest being 0. Overall, the Herfindahl indices suggest that the average OPO market was somewhat more monopolistic than competitive.

The mean proportion of patients that were listed in Status 1 or 1A was 17.9%. Figure 2 plots this proportion against the Herfindahl index. The negative slope of the fitted regression line suggests that centers in more competitive OPOs tend to list more patients as Status 1 and 1A. In fact, the average proportion of Status 1 or 1A listings among the 15 monopolistic TCs is 14.8% while the average proportion for the 15 centers in the most competitive OPOs is 19.8%, an increase of 34%.

We next fit the data to random effects models, regressing the logit of the proportion of Status 1/1A patients on our covariates as described above. Table 3 presents results for the 1995-1998 data. Two sets of results are presented, corresponding to the two Herfindahl index measures. Model 1 contained the Status 1 Herfindahl index, computed from shares of Status 1 patients on the waiting list, and model 2 contains the total list Herfindahl index, computed from shares of all patients on the waiting list. Note that in both models, TCs with higher proportions of female patients and patients with blood type O, listed fewer Status 1 patients, but these coefficients were not significantly different from zero. Consistent with our observation in Table 1 that, in general, more patients were listed as Status 1 over time, the year dummy variables suggest that the proportion of patients listed as Status 1 was significantly higher in 1998 than in 1995 or 1996. Finally, the coefficient of the Waiting List Herfindahl index is negative and statistically significant, suggesting that TCs in more competitive OPOs, as defined by Status 1 listings, are significantly more likely to list their patients as Status 1. The coefficients suggest that each 0.25 point reduction in the Status 1 Herfindahl index will decrease the odds of listing patients in Status 1 by 17% at an average TC. For example, a drop in the Herfindahl index from 0.75 to 0.5 would result in an increase in the proportion of patients listed as Status 1 from 15.9% to 18.2%. The coefficients in Model 2 suggest that each 0.25 reduction in the Waiting List Herfindahl will increase the odds of listing patients as Status 1 by 7.8%, but this effect was not statistically significant.

In Table 4 we present results from fitting the random effects model to the 1999-2000 data. As seen in the table, the coefficients for both Herfindahl indices were negative, suggesting that TCs in more competitive OPOs were more likely to list their patients in Status 1A. A 0.25 decrease in the Status 1A Herfindahl is associated with an increase the odds of an average center listing a patient as Status 1A of 3.5%, and the same decrease in the Waiting List Herfindahl is associated with an increase in the odds of listing Status 1A patients of 5.4%. While the signs of the coefficients are consistent with our hypothesis, the magnitude of the effects are small and only the intercepts are statistically significant in the 1999-2000 data. Collectively, the models presented in Tables 3 and 4 explain very little (1-5%) of the total variation in highest severity listings.

Next, data for all years were pooled and fit to a random effects model that also included a dummy variable that was coded for the UNOS listing status change in 1999, and an interaction between this dummy and the Herfindahl indices. Results in Table 5 suggest that listing practices of TCs are significantly associated with competition within the OPO, particularly prior to the change in listing status categories. The coefficient for the Status 1 Herfindahl index is negative and statistically significant and suggests a 0.25 reduction in the Status 1/1A Herfindahl would increase the odds by 16.9% of a center listing its patients as Status 1, and 8.7% of a center listing its patients as Status 1A. Furthermore, a 0.25 reduction in the Waiting List Herfindahl would result in a 7.3% increase in the proportion of Status 1 patients and a 4.3% increase in the proportion of Status 1A patients at an average TC. The pooled model explains 10% of the total variation in the dependent variable. In order to estimate this model, the 1995 and 1999 observations were dropped in order to avoid perfect correlation with the UNOS policy dummy variable.

Finally, to test whether competitors' general tendency to list patients in the highest severity category influenced a TC's listing decisions, we estimated a model that included the lagged percentage of total OPO listings that were in the most severe category (Status 1 or Status 1A). The results of this model are presented in Table 6 and are consistent with previous findings. First, the centers in OPOs that have relatively higher proportions of patients listed in the most severe listing categories, had significantly higher proportions of patients listed in the most severe status in the following year. Again, the Herfindahl based on listing status was negative and significant, but the Herfindahl index based on total listings was negative, but smaller in magnitude and not statistically significant.

VI. Discussion:

These results have several important implications. First, when competition is measured by the HHI on Status 1 or Status 1A, TCs do appear to respond to a more competitive OPO environment by listing relatively more patients in the most severe listing status. Since this status is not completely subjective, it is likely that specific resources are used to justify the status, including the implantation of LVADs, early admission to the ICU, and the use of specific drug regimens such as inotropes, which raises the possibility of unnecessary procedures and potentially wasted resources. Although the potential incentive for such behavior has been described previously, and there exists anecdotal evidence that gaming takes place, this is the first empirical evidence that links TC listing practices to OPO competition.

Second, the type of within-OPO competition matters. TCs are more sensitive to competition defined in terms of Status 1/1A listings at other centers within their OPO than competition defined in terms of total patients on the waiting list. The fact that the effect of competition defined in terms of Status 1/1A patients was both larger and statistically significant than the effects of competition defined by the size of the total waiting list, suggests that the type of competition matters. TCs evidently do not consider competition to be another transplant center with a large waiting list *per se*, but rather another transplant center with a relatively large proportion of Status 1/1A patients. This conclusion is also supported even after controlling for the lagged proportion of listings in the highest severity category in the market.

Finally, the propensity of TCs to respond to within-OPO competition was more evident prior to the change in listing status categories in 1999. Although the policy change was not specifically devised to thwart potential list gaming, it is possible this was a potentially beneficial consequence. Coefficients on the competition measures in regressions using data from the Status 1A/1B/2 era are consistently negative, supporting our hypothesis of competitive behavior, but the magnitude of the effects was small—much smaller than regressions from the Status 1/2 era—and the effects were not statistically significant. The lack of statistical significance may be attributable to the fact that the new status structure may make it more difficult to upstage marginal patients. However, it may also be simply a sample size issue given the small effect size. More data and additional research are necessary to resolve whether the incentive to game the allocation mechanism persists in the new era of the Status 1A and 1B listing categories.

Several limitations and caveats to our analysis deserve mention. The first pertains to the best method for accounting for very small TCs (in terms of both total patients listed and total transplants performed). In our market analysis, this amounts to determining whether a TC is truly a competitor in the market. Future work will address this issue empirically by choosing different thresholds for dropping observations, and by estimating weighted regressions.

A second limitation pertains to the fact that our data represents aggregated data for all listed and transplanted patients within a TC. For example, our dependent variable is calculated from data that represents the average number of patients listed in each category on any given day during the calendar year. Likewise, our explanatory variables represent the average proportion of patients that were male or female, or of a given blood type. Ideally one would want the most disaggregated level of data, which would be patient level data for each TC. However, due to UNOS data restrictions, we were unable to obtain the disaggregated data. Hence, our analysis is limited by the fact that we can only control for aggregate patient level characteristics. Future research might strive to obtain patient level data.

A third limitation relates to the potential bias due to important omitted explanatory variables. Other studies that have examined aspects of heart transplantation have included such other covariates as the percentage of patients removed from the status 1 (or 1A) waiting list, center specific survival rates, the percentage of a patient's waiting time on status 1 or 1A, percentage of repeat transplantations, medical condition at the time of transplantation, proportion of patients with congenital heart disease, transplant training for cardiologists, presence of a transplant coordinator, distance from patients' home to the transplant center, ventricular assistance, use of inotropes, and intensive care unit admission. These variables are not included in our study because they were unavailable. In addition, since some of these variables would be endogenous with our dependent variable, we would not want to include these even if they were available. For example, we hypothesize that LVADs and inotropes are used to credibly move patients up the list, and that patients who are upstaged may survive longer since they are in better health.

A fourth limitation is actually the result of the very policy change that we are trying to model. In other words, we wish to examine whether UNOS' listing changes exacerbated or mitigated listing practices associated with TC competition that might have been occurring prior to 1999. Although the research question seems amenable to a pre-post comparison, the policy change fundamentally affected the main outcome variable we are interested in, namely the proportion of patients listed in the highest severity category. Prior to 1999, that category was status 1, while it became status 1A after the policy change. So, our analysis must consider whether we can treat these categories as equivalent for purposes of modeling, which influences whether we are able to analyze the data by pooling all the years, or whether we must analyze the data separately for the pre-policy and post-policy years. For the latter, we also must decide whether we can interpret changes in the magnitude, sign, or significance of the coefficient on the competition variable as due to the policy change.

Because of these limitations, our results should be interpreted cautiously. Nonetheless, it is important for researchers and policymakers to consider whether competition among TCs is efficient, both in terms of the costs of transplantation, as well as the equity of scarce donor heart allocation. If competition provides an incentive for TCs to 'upgrade' their listing signal, primarily by means of unnecessary expensive medical intervention (e.g., placing patients in the intensive care unit or using pharmaceuticals or mechanical assistance), then competition should be viewed as inefficient, since it ultimately would result in the wrong patients being transplanted at higher costs. Evidence regarding fixed and variable costs is crucial for determining potential resource economies from consolidating volume in fewer centers.

However, it is also important to consider the possibility that the United States' transplant capacity is not the problem, but instead the lack of a sufficient number of donor hearts is the problem. The American Medical Association's Council on Ethical and Judicial Affairs recently raised this issue in a controversial fashion, suggesting that an experiment should be conducted to determine if paying relatives of deceased organ donors would increase the supply of transplantable organs [Healthnews, (2002)]. Although a more detailed discussion of these policy issues is beyond the scope of this paper, we hope that our analysis can help inform those discussions.

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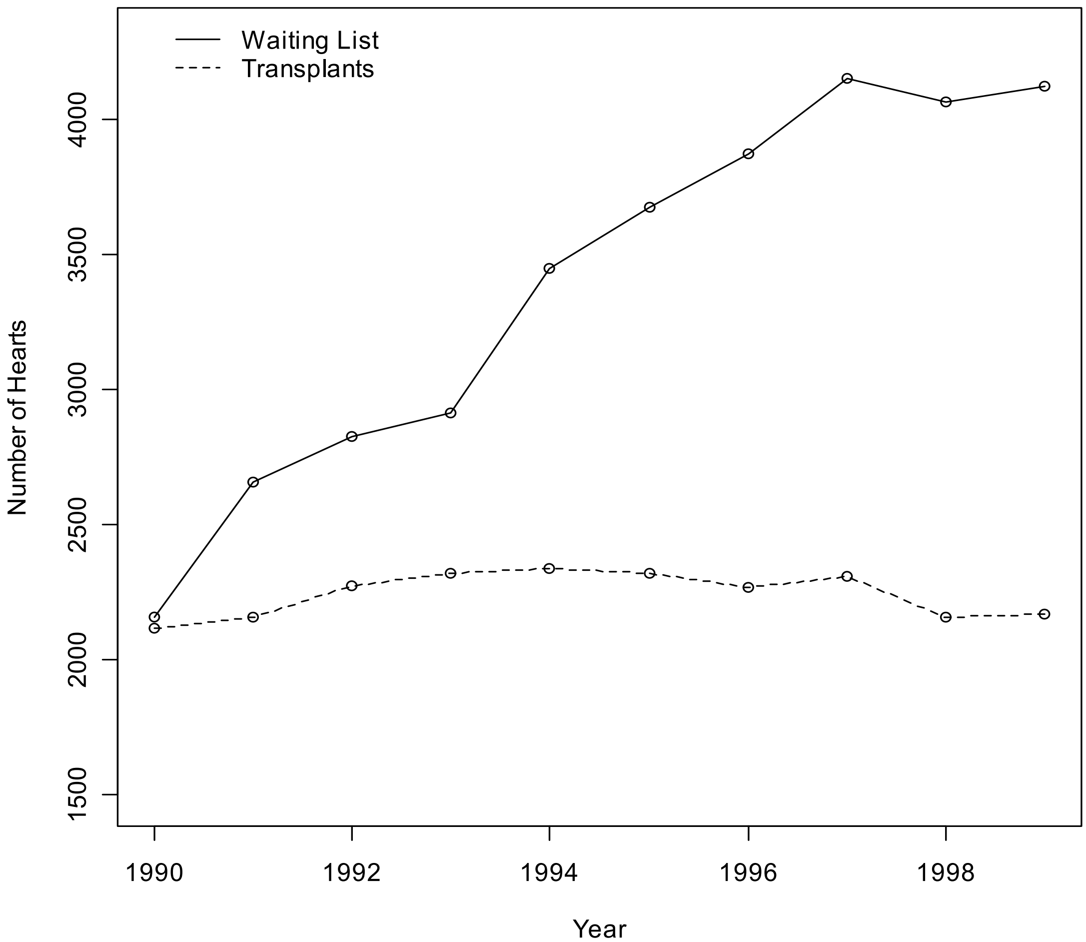
Figure 1: Supply and Demand for Hearts, 1990-1999



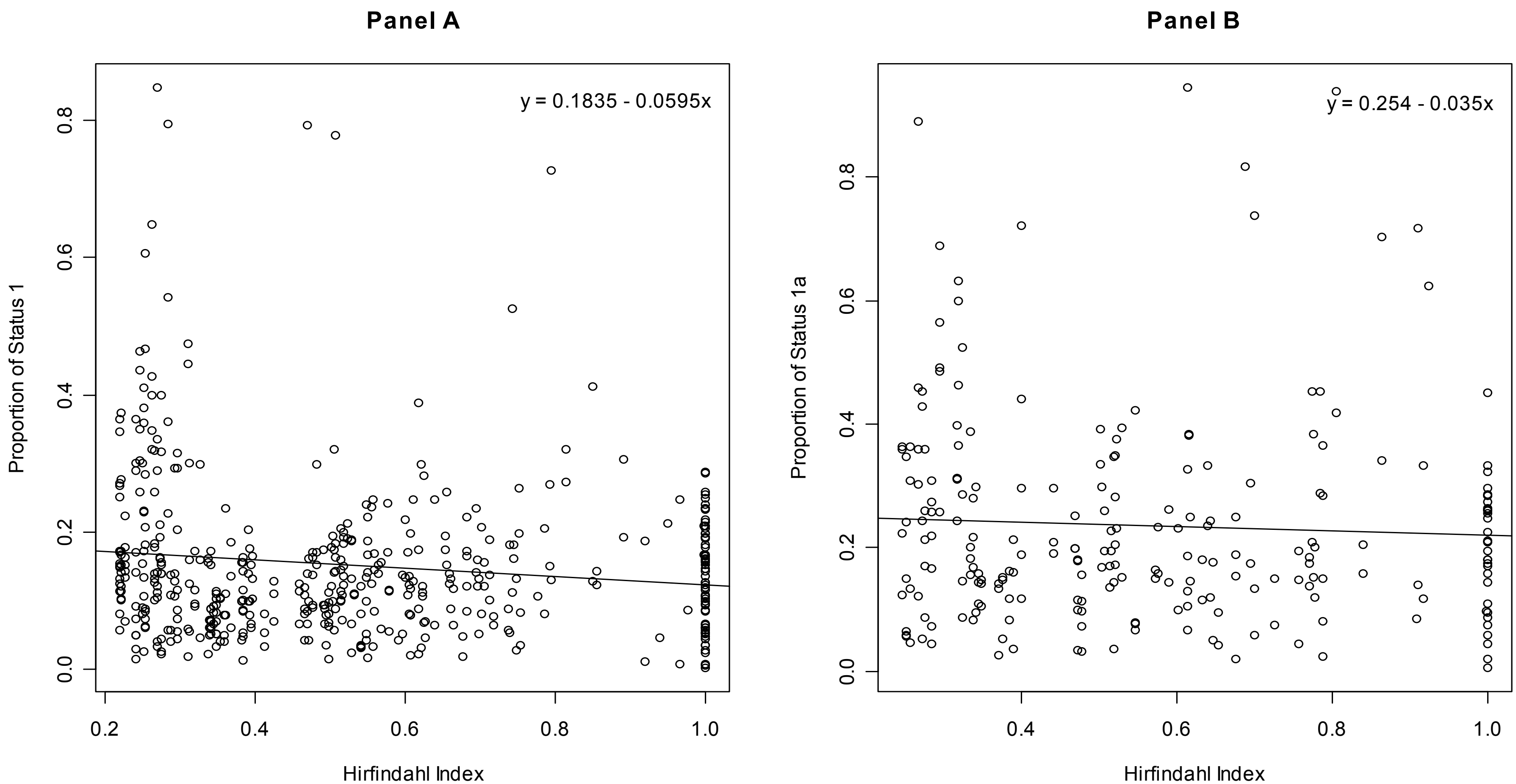


Figure 2: Correlation between Herfindahl index and proportion of listings in Status 1 (Panel A) and correlation between Herfindahl index and proportion of Status 1a listings in 1999-2000 (Panel B)

Table 1: Transplant Center Descriptive Statistics

Variable	Year	N (Centers)	Mean	Standard Deviation	Minimum	Maximum
Total Transplants	1995	129	17.51	15.32	0	81.0
	1996	126	17.70	15.63	0	97.0
	1997	123	17.75	16.53	0	102.0
	1998	125	18.16	17.60	0	113.0
	1999	128	16.24	14.10	0	83.0
	2000	120	17.64	16.23	0	101.0
Percent Female	1995	129	18.0%	0.0074	0	1.00
	1996	126	18.0%	0.0072	0	0.76
	1997	123	19.0%	0.0074	0	0.86
	1998	125	20.0%	0.0074	0	0.57
	1999	128	20.0%	0.0079	0	0.71
	2000	120	20.0%	0.0079	0	0.70
Percent O Blood Type	1995	129	56.0%	0.010	0	0.85
	1996	126	54.0%	0.009	0	0.87
	1997	123	55.0%	0.009	0	0.95
	1998	125	55.0%	0.009	0	1.00
	1999	128	55.0%	0.010	0	1.00
	2000	120	58.0%	0.010	0	0.85
# Patients Listed Status 1	1995	129	1.82	2.10	0	13.00
	1996	126	2.42	2.95	0	14.61
	1997	123	2.71	3.13	0	17.38
	1998	125	3.22	4.03	0	24.14
# Patients Listed Status 1a	1999	128	0.68	0.97	0	6.71
	2000	120	0.78	1.03	0	6.49
# Patients Listed Status 1b	1999	128	2.79	3.19	0	17.49
	2000	120	3.09	3.56	0	20.53
# Patients Listed Status 2	1995	129	14.45	14.31	0	72.64
	1996	126	16.18	16.99	0	89.08
	1997	123	16.32	18.82	0	94.89
	1998	125	16.12	18.67	0	103.99
	1999	128	15.55	19.29	0	105.68
	2000	120	15.69	20.12	0	118.99
% Patients Listed Status 1	1995	129	13.0%	0.13	0	1.00
	1996	126	14.0%	0.12	0	1.00
	1997	123	15.0%	0.12	0	0.85
	1998	125	19.0%	0.16	0	1.00
% Patients Listed Status 1a	1999	128	4.8%	0.0924	0	1.00
	2000	120	4.9%	0.0514	0	0.33

Table 2: Market (OPO) Descriptive Statistics

Variable	Year	N (OPOs)	Mean	Standard Deviation	Minimum	Maximum
Total Transplant Centers per OPO	1995	41	2.46	1.23	1	5
	1996	37	2.38	1.28	1	5
	1997	37	2.32	1.29	1	5
	1998	38	2.53	1.43	1	6
	1999	40	2.32	1.27	1	5
	2000	38	2.18	1.23	1	5
	Overall	*231*	*2.37*	*1.28*	*1*	*6*
Herfindahl Index (Total List)	1995	41	0.64	0.29	0.22	1
	1996	37	0.66	0.29	0.22	1
	1997	37	0.67	0.30	0.25	1
	1998	38	0.67	0.29	0.25	1
	1999	40	0.69	0.28	0.27	1
	2000	38	0.71	0.28	0.25	1
	Overall	*231*	*0.67*	*0.28*	*0.22*	*1*
Herfindahl Index (Status 1 List)	1995	41	0.63	0.30	0	1
	1996	37	0.62	0.30	0	1
	1997	37	0.65	0.30	0	1
	1998	38	0.65	0.30	0.24	1
	Overall	*153*	*0.64*	*0.30*	*0*	*1*
Herfindahl Index (Status 1a List)	1999	40	0.67	0.30	0	1
	2000	38	0.66	0.31	0	1
	Overall	*78*	*0.67*	*0.30*	*0*	*1*

Table 3: Random Effects Model Results, Pre-Policy Change (1995-1998)

	Model 1			Model 2		
Variable	*Coefficient*	*Standard Error*	*P-value*	*Coefficient*	*Standard Error*	*P-value*
Constant	-1.1841	0.251	0.0000	-1.4100	0.261	0.0000
$\text{Herfindahl}_{\text{Status 1 Listings}}$	-0.6432	0.256	0.0119	-	-	-
$\text{Herfindahl}_{\text{Total Listings}}$	-	-	-	-0.3013	0.265	0.2562
Blood Type O (%)	-0.1676	0.265	0.5264	-0.1492	0.266	0.5745
Female (%)	-0.4468	0.308	0.1464	-0.4405	0.309	0.1537
1995 Dummy	-0.4670	0.099	0.0000	-0.4755	0.100	0.0000
1996 Dummy	-0.3116	0.099	0.0017	-0.3089	0.100	0.0020
1997 Dummy	-0.1797	0.099	0.0700	-0.1852	0.100	0.0629
R^2	0.0528			0.0478		
N	483			483		

Table 4: Random Effects Model Results, Post Policy Change (1999-2000)

Variable	Model 1 Coefficient	Model 1 Standard Error	Model 1 P-value	Model 2 Coefficient	Model 2 Standard Error	Model 2 P-value
Constant	-1.2619	-3.256	0.0011	-1.2056	0.404	0.0028
$\text{Herfindahl}_{\text{Status 1 Listings}}$	-0.1387	-0.354	0.7230	-	-	-
$\text{Herfindahl}_{\text{Total Listings}}$	-	-	-	-0.2108	0.407	0.6044
Blood Type O (%)	0.2065	0.500	0.6174	0.1946	0.414	0.6385
Female (%)	-0.4930	-1.005	0.3148	-0.4828	0.488	0.3228
1999 Dummy	-0.1232	-1.072	0.2839	-0.1304	0.116	0.2588
R^2	0.0105			0.0100		
N	229			229		

Table 5: Random Effects Model Results, (All Years Pooled)

Variable	Model 1			Model 2		
	Coefficient	*Standard Error*	*P-value*	*Coefficient*	*Standard Error*	*P-value*
Constant	-1.2879	0.236	< 0.0001	-1.5161	0.247	< 0.0001
$\text{Herfindahl}_{\text{Status 1/1a Listings}}$	-0.6248	0.249	0.0121	-	-	-
$\text{Herfindahl}_{\text{Total Listings}}$	-	-	-	-0.2800	0.267	0.2942
Blood Type O (%)	0.0018	0.224	0.9937	0.0210	0.223	0.9250
Female (%)	-0.4066	0.265	0.1242	-0.3824	0.263	0.1454
1995 Dummy	-0.4630	0.105	< 0.0001	-0.4703	0.105	< 0.0001
1996 Dummy	-0.3156	0.106	0.0030	-0.3124	0.106	0.0031
1997 Dummy	-0.1811	0.106	0.0877	-0.1854	0.106	0.0790
(1999-2000)*Herfindahl	0.2903	0.267	0.2777	0.1127	0.265	0.6705
1999-2000 Dummy	0.1842	0.173	0.2882	0.2717	0.175	0.1196
R^2	0.1019			0.0992		
N	712			712		

Table 6: Random Effects Model Results: (All Years Pooled - Lagged OPO Ratio of Status 1/1A*)

Variable	Model 1 Coefficient	Model 1 Standard Error	Model 1 P-value	Model 2 Coefficient	Model 2 Standard Error	Model 2 P-value
Constant	-1.4499	0.227	< 0.0001	-1.6219	0.237	< 0.0001
Lagged OPO 1/1A Ratio	0.0003	0.000	0.0003	0.0003	0.000	0.0002
$\text{Herfindahl}_{\text{Status 1/1a Listings}}$	-0.4887	0.231	0.0341	-	-	-
$\text{Herfindahl}_{\text{Total Listings}}$	-	-	-	-0.2366	0.248	0.3409
Blood Type O (%)	-0.0148	0.228	0.9483	0.0008	0.228	0.9970
Female (%)	-0.4025	0.268	0.1335	-0.3729	0.268	0.1645
1999-2000 Dummy	0.5802	0.077	< 0.0001	0.5760	0.078	< 0.0001
1996 Dummy	-0.2198	0.101	0.0295	-0.2191	0.101	0.0304
1997 Dummy	-0.0876	0.101	0.3850	-0.0929	0.101	0.3572
R^2	0.095			0.092		
N	469			469		

* Dummy variable for 1995 has been omitted to accommodate the lagged independent variable.